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Spatial opportunistic transmission for Quality of Experience satisfaction ☆

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ABSTRACT

The capability of Multiple Input Multiple Output (MIMO) to deliver service simultaneously to more than one user is an exceptional characteristic for the cognitive radio (CR) communication. In this paper, statistical optimization techniques are applied to assess the performance of the Quality of Experience (QoE) in CR systems, where each user has different demands. The Multiuser scenario is considered where the transmitter runs the Multibeam Opportunistic Beamforming technique to service more than one user. Closed form expressions are derived for different scenarios and obtained for four QoE indicators in the system. The performance of primary and secondary users in such scenarios are mathematically formulated and the results are compared with computer simulations.

1. Introduction

The radio spectrum is becoming more occupied as the demand on wireless applications is explosively increasing, which presents a significant challenge for the operators to obtain the sufficient bandwidth that can handle them. Flat-rate download over wireless is not anymore a feasible option for its practical implementation by the wireless carriers, as the users demands would collapse the network. On the other hand, several surveys have revealed that this precious resource is widely under-utilized [1,2].

This fact motivated the research field to investigate on new techniques and mechanisms to boost the spectrum efficiency and to increase its occupancy. The idea of cognitive radio [3] emerged as a smart technique for spectrum sharing, by allowing lower priority users to access the medium reserved for high priority users, at the same time, frequency and code. All of that without affecting the quality performance of the high priority users.

Even cognitive radio gained a large momentum and it is one of the main techniques for new standardization bodies, but it still faces many challenges for its commercial implementation. Such adoption by the commercial systems needs flexibility in the allocation process that must be highly dynamic and fast i order to adapt to the continuous environment and demands scenario, in order to avoid harmful effect from the secondary (low priority) users on the primary (high priority) users, in order to fulfill the ultimate goal of employing cognitive radio [3].

A well established technology is Multiple Input Multiple Output (MIMO) systems, where transmitters and/or receivers are equipped with several antennas (more than one) and the signals flow over the wireless link using several interfering paths. Novel and complex techniques [4] have been developed over the past years for the MIMO technology to boost the performance of wireless systems in order to offer higher throughput, lower error probability, and enable interference cancellation for simultaneous multiuser transmissions.

Another application of MIMO systems is to enable cognitive radio in the spatial domain, the so called "Spatial Sharing"; where a user can be serviced through the first antenna/stream while another user via the second antenna/stream as long as it does not affect the Quality of Experience (QoE) satisfaction [5] of the first user. MIMO systems need Channel State Information at the Transmitter (CSIT) in order to obtain all its promised benefits, but CSIT is very complicated in commercial systems because of the required signalling, and more in Multiuser scenarios. Partial CSIT [6] seems to be the most suitable case to grasp MIMO benefits while being implementable, and the Multibeam Opportunistic Beamforming (MOB) [6] is one of the main techniques that adapts to partial CSIT, while showing very good performance. The idea of cognition is very

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known [3], but its application within the spatial domain is relatively immature. Its consideration is mainly motivated by the inclusion of MIMO antennas in broadband wireless communication standards [7].

The main idea of spatial cognition is to separate the serviced users only through their spatial signature (i.e., their channel impulse response), while communicating at the same time, frequency and code. As it is aforementioned, low priority users called Secondary Users (SU) will access the same resources allocated to high priority users called from now on Primary Users (PU), without affecting the QoE behavior for the PU. Therefore, more than one user will be serviced in comparison to old systems where only PUs are allowed to access the system. This means that two contradicting goals should be optimized: maximizing the throughput of SU (i.e., the cognitive users) while reducing the interference to the PUs.

The availability of CSIT in the multiuser allocation process enables to extract the diversity gain, which enhances the system performance. In [8], CSIT is incorporated in their scheduling scheme, while providing delay constraints for packets. Moreover, [6,9] evaluate the maximum delay that faces the worst channel user in the system. Nevertheless, these works do not consider the imposed priority levels by the cognition concept. To the best of our knowledge, few studies have focused on QoE provisioning in CR systems with multiple antennas [10], and their preliminary results focus on the secondary user satisfaction from the delay perspective.

The users' heterogeneity (i.e., PU and SU) as well as their running applications constitute a wide range of requests that the operator has to accomplish in order to satisfy its users' QoE needs. QoE has two main mechanisms for its evaluation: objective and subjective methods [11,12], where subjective methods depend on human observations to evaluate quality levels, and they are usually set up in real (controlled) life environments [13,14] and depend on real users experience, that can be easily biased [13,15]. On the other hand objective methods give more consistent evaluations [16] from the engineering point of view, as they are based on engineering metrics from the network itself [16]. In this case, predefined metrics are set up on the basis of users satisfaction and the price that the users pay for the service, and any new scheme/algorithm should meet these predefined values. Obviously, both subjective and objective methods have to be developed in order to reach the final objective of QoE to the users, with mathematical expressions that link between the two approaches. In this paper, we focus on the objective method and how to achieve predefined QoE metrics through the implementation of a hybrid MIMO-Cognitive communication strategy.

The objective of this paper is to provide quantitative QoE results that are based on the network performance satisfaction metrics, where we will present the QoE in terms of the minimum guaranteed rate, the maximum allowed scheduling delay and jitter. Previous studies have shown that the user's satisfaction is insignificantly increased by a performance higher than the requested demands, while on the other hand, if the user's requirements are not fulfilled then the satisfaction is drastically reduced [17].

In this paper, QoE within the spatial cognitive scenario is investigated, where the multiple antennas are employed by the MOB scheme to service more than one users at the same time, so that one PU is serviced as well as other SUs. We characterize the statistical distributions for the developed scenario in order to fully characterize the proposed scheme and all its parameters. The main contributions of the paper are:

- A spatial cognition scenario is analyzed where the MOB strategy is employed. The opportunistic scheduling is considered in order to select the serviced users at each time.
- The statistical distributions (Probability Density Function (PDF) and Cumulative Density Function (CDF)) are obtained within the proposed multiuser scenario.
- QoE metrics [16] based on maximum allowed scheduling delay, minimum guaranteed throughput and mean jitter are obtained in closed form expressions, to show the impact of each parameter in the system performance, and to optimize it.

The rest of this paper is organized as follows: in Section 2 the system model is presented while in Section 3 a revision for MOB is tackled together with its adaptation to the cognitive radio philosophy. Section 4 discusses the QoE metrics in the cognitive scenarios, while the numerical and simulation results are displayed in Section 5, followed by the paper conclusions in Section 6.

2. System model

We focus on a single cell Downlink channel where N users, each one of them equipped with a single receiving antenna, are being served by a transmitter at the Base Station (BS) provided with n_t transmitting antennas, and supposing that N is greater than n_t. The total number of users is divided in two classes: PU denoted as N_{PU} and SU referred to as N_{SU}. The considered scenario is actually a multiuser Multiple Input Single Output (MISO) but the results can be easily applied to multiuser MIMO with any receiver processing. This scenario is considered for easiness, as the receiver processing is out of this paper scope, and all main conclusions of the paper are independent of the processing carried out at the receiver.

A wireless multiantenna channel $\mathbf{h}_{[1\times n_t]}$ is considered between each of the users and the BS, where a quasi-static block fading model is assumed, which keeps constant through the coherence time, and independently changes between consecutive time intervals with independent and identically distributed (i.i.d.) complex Gaussian entries $\sim \mathcal{CN}(0,1)$. Let $\mathbf{x}(t)$ be the $n_t \times 1$ transmitted vector, while denote $y_n(t)$ as the n^{th} user received signal, given by

$$y_n(t) = \mathbf{h}_n(t)\mathbf{x}(t) + z_n(t) \tag{1}$$

where $z_n(t)$ is an additive Gaussian complex noise component with zero mean and $E\{|z_n|^2\} = \sigma^2$. The transmitted signal $\mathbf{x}(t)$ encloses the independent data symbols $s_m(t)$ to each one of the selected users with $E\{|s_m|^2\} = 1$. A total transmitted power constraint $P_t = 1$ is considered, and for ease of notation, time index is dropped whenever possible.

3. Multibeam Opportunistic Beamforming (MOB)

One of the main transmission techniques in multiuser multiantenna scenarios is the MOB scheme [6], where random beams are generated at the BS to simultaneously serve more than one user. The beam generation follows an orthogonal manner to decrease the interference among the served users, where n_t beams are generated. Within the acquisition step, a known training sequence is transmitted for all the users in the system. Therefore, each user sequentially calculates the Signal-to-Noise-Interference-Ratio (SNIR) related to each beam, and feeds back to the BS only the best SNIR value together with an integer number indicating the index of the selected beam. The BS scheduler chooses the user with the highest SNIR value for each one of the beams. So, it gets the multiuser gain from the scenario to increase the system throughput. After that, the BS enters into the transmission stage and simultaneously transmits to each one of the n_t selected users, where no user can obtain more than one beam at a time.

Along the paper, all the users are assumed to have the same average channel characteristics, and showing the same distribution for the maximum SNIR value, so that each user has the same probability to be selected. If this is not the case (e.g., heterogeneous